Use of Quality Tools and Standards for Continuous Improvement in Engineering Education

R. Radharamanan[1]

Abstract

This paper provides an overview of how best the quality principles, quality tools, and ISO-9000 standards could effectively be used in improving the quality of engineering education. The use of quality tools in engineering education as well as a comparison of EC-2000 with ISO-9000 standards are presented and discussed for achieving continuous improvement in the quality of engineering education. The "*outcomes assessment*" model concepts of EC-2000 were applied in two manufacturing courses at the Mercer University School of Engineering (MUSE) for continuous improvement in students' learning. The documented information over a period of four years, the results obtained through statistical analysis, and a comparison on outcomes in students' learning between these two courses are presented and discussed.

Introduction

The total quality management principles along with the quality tools such as flow charts, cause-and-effect diagram, Pareto diagram, control charts, and quality function deployment could effectively be used to monitor the quality of engineering education. EC-2000 emphasizes that each program must have an assessment process with documented results. In particular, it demands that academic programs be engaged in continuous improvement cycles based on assessment data. The emphasis on the use of assessment data to guide improvements in the educational processes is consistent with the current trends and calls for quality and accountability of educational systems. There has been significant interest in the broad applications of quality management in higher education. However, EC-2000 is a focused attempt to bring quality assurance to the field of engineering education in a very formal and direct manner. EC-2000 promotes the innovation and continuous improvement of engineering education. The assessment process must demonstrate that the outcomes important to the mission of the institution and the objectives of the program are being measured. ISO-9000 quality standards provide guidelines for structuring quality assurance system and are used for any business. EC-2000 is specific to engineering education. There are similarities and differences between EC-2000 and ISO-9000 standards. Some of the lessons learned in the ISO-9000 field could easily be extended to engineering education and EC-2000. In this paper, the "*outcomes assessment*" model concepts of EC-2000 have been applied in two manufacturing courses (ISE 370: Manufacturing Processes I, and ISE 424: Computer Assisted Manufacturing Systems) at Mercer School of Engineering for continuous improvement in students' learning. The documented information for a period of four years (1998-2002), the steps taken for continuous improvement in students' learning, the results obtained through statistical analysis, and a comparison on outcomes in students' learning between these two courses are presented and discussed.

Quality Tools and ISO-9000 Standards

Quality is a competitive advantage in the marketplace. This means that a company must have the same or better quality than its competitors. The quality of competitors, however, is improving continuously. This situation keeps a company improving quality continuously to remain a viable force in the market place.

[1] Department of Mechanical and Industrial Engineering, Mercer University, Macon, GA 31207-0001, USA

Companies can no longer tolerate adverse gaps in product quality between their products and those of their competitors. To prevent this, a viable program of continuous improvement must be developed and put into practice [14].

There is tremendous overlap between total quality management (TQM) in manufacturing and institutional effectiveness in higher education. For example, the Southeastern Universities and Colleges Coalition for Engineering Education (SUCCEED) proposed a 10-step quality management support model in support of engineering education reform [1], and a quality management plan based on service quality had been developed and implemented at Indiana University Southeast [2].

A series of innovative quality planning approaches important for the success of comprehensive quality planning model have been presented and supported by data from a case study for the first-year curriculum at Texas A&M University. It has been verified that the inclusion of concepts from systems engineering, quality function deployment (QFD), quality management, and utility theory can not only prove useful in strategic planning but also assist the decision-making team by taking into account the voice of the customer as the primary source of information input [4].

The quality of education will not be met until a quality culture is developed. Success can only be achieved when everyone involved in engineering education has the commitment, the motivation, and the means to incorporate the culture of quality in every lecture, every laboratory work that is supervised, … , or every paper that is written [3]. Self-assessment of quality in classroom processes and systems is essential to promote continuous improvement and customer satisfaction. For example, the total quality management concepts were applied to improve the quality of higher education in Lamar University [10]. The planning phase of PDSA (plan-do-study-act) has been applied for quality improvement. The three steps used were to perform SIPOC (supplier, inputs, process, outputs, and customers) to flow chart the process, generate data on the output of the process and quality problems, and analyze the data and provide quality improvement recommendations.

The objective of the project on the University Enterprise Partnership for Total Quality Management (UE-TQM-P) [7] was to fill the gap between the demands of business and the knowledge, skills and attitudes about TQM being provided to students by institutes of higher education. The study identified eight important quality concepts and skill categories: customer orientation; practical knowledge and application of TQM tools; fact based decision making; an understanding of work as a process; team orientation; commitment to improvement; active learning; and systems perspective.

ISO-9000 standards exist principally to facilitate international trade. The driving forces that have resulted in widespread implementation of ISO-9000 standards can be summed up in one phrase: “the globalization of business”. Expressions such as “post-industrial economy” and “the global village” reflect profound changes during recent decades [6]. These changes include: new technology in virtually all industry/economic sectors; worldwide electronic communication network; widespread worldwide travel; dramatic increase in world population; depletion of natural resource reserves; more intensive use of land, water, energy, and air (widespread environmental problems/concerns); downsizing of large companies and other organizations; number and complexity of language, culture, legal, and social frameworks encountered in the global economy with diversity being a permanent key factor; and developing countries becoming a larger proportion of the total global economy with new kinds of competitors and new markets. These changes have led to increased economic competition, increased customer expectations for quality, and increased demands upon organizations to meet more stringent requirements for quality of their products.

The Vision 2000 report proposed four goals that relate to maintaining the ISO-9000 standards so that they continually meet the needs of the market place [6]. These goals are *universal acceptance*, being adopted and used worldwide; *current compatibility*, facilitating combined use without conflicting requirements; *forward* *compatibility*, with successive revisions being accepted by users; and *forward flexibility*, using architecture that allows new features to be incorporated readily.

The ISO quality standards do not refer directly to the products or services delivered, but rather to the production and administrative processes that produce them. It is generic enough to be applicable to any industry type. Specifically, the standards focus on the need for organizational structure, well-documented procedures, and management's commitment of resources to implement quality management [13]. The 20 clauses of ISO-9001 standard, the most comprehensive of the three standards are found in [8, 11].

ISO-9000 certification occurs when a neutral and independent "registrar" uses one of the ISO-9000 standards to certify a supplier. This results in an official designation of the supplier as an "ISO-9001 or ISO-9002 or ISO-9003" certified supplier. A supplier registered in this manner is in the enviable position of being seen as a reliable worldwide supplier of quality products and services; its customers can reduce or eliminate inspection of purchased parts thereby resulting in an efficient system of global trade [13]. Quality assurance in engineering education as well as continuous improvement in students' learning can be achieved by incorporating some of the lessons learned in the ISO-9000 field such as focusing on the processes instead of the inputs and outputs, importance of documentation and training, and customer focus.

New ABET Criteria: EC-2000

The new ABET criteria represent a major shift in the philosophy behind accreditation of engineering programs. EC-2000 is changing dramatically the manner in which engineering programs assess their curricula, interact with its constituents, and seek ABET accreditation.

EC-2000 is composed of eight criteria that emphasize quality and professional preparation maintaining the traditional core of engineering, math, and science requirements, but also placing importance on a set of new skills that includes teamwork as well as global, economic, social, and environmental awareness. EC-2000 requires academic programs to define and measure desirable outcomes of their graduates. A set of eleven specific outcomes ("a" through "k") is deemed minimally essential under EC-2000. Each engineering program must have an assessment process with documented results. The assessment process must demonstrate that the outcomes important to the mission of the institution and the objectives of the program being measured [5]. The outcome assessment program developed by the College of Engineering at Georgia Tech which served as a pilot program for the new engineering accreditation criteria consisted of: program mission/vision statement; program educational objectives; program outcomes; program strategies and assessment methods; and use of results.

The following seven suggestions were offered for those preparing for an assessment-based accreditation visit such as EC-2000:

1. First focus on what is important to the college and then focus on what is important for accreditation.
2. Improve the existing assessment process and measures.
3. Share information and collaborate as much as possible.
4. Clarify terminology and establish the key elements of the assessment plans early in the development process.
5. Identify benchmark institutions and key constituents.
6. Gather data and lots of it.
7. Develop a system to document the use of results.

Preparing for ABET is now a continuous process and it will require constant effort after the team leaves [9].

While developing assessment plans to implement continuous quality improvement of EC-2000, there is a concern about what measures are adequate to provide evidence that an engineering program is meeting its stated objectives [12]. It is necessary to identify educational inputs, processes, outputs, and outcomes to clarify focus of the new "*outcomes assessment*" model of engineering education accreditation. The elements of the model with reference to students, faculty, and institution are listed in Table 1.

Table 1: Elements of outcomes assessment model*

Elements	Students	Faculty	Institution
Inputs	Academic credentials Test scores Attitudes and values Personal competencies	Academic credentials Life experiences Attitudes and values	
Processes	Major chosen Course taking patterns Co-curricular participation	Teaching load Class size Professional development Research activities Community services	Programs and services (both academic and non-academic) Policies Procedures Governance
Outputs	Retention rates GPA of graduating class Employment statistics Graduate school statistics Alumni support	Number of publications Research dollars Professional conferences	Use of resources Participation rates Facilities usage
Outcomes	Cognitive growth Skills attained Attitudes developed	Publication citations Contribution to the field Achievement of advisees	

*Adapted from Rogers [12].

The "*inputs*" of an educational system are those things that are brought into the educational settings. The "*processes*" focus on what is happening with the inputs. The "*outputs*" can best be characterized by "how many" or what tangible products are there from the processing of the organizational inputs. The "*outcomes*" of the educational experience are those things that answer the question, "What is the effect?"

TQM in Education and Comparison between ISO-9000 and EC-2000

The following are the guidelines for the development of Total Quality Management (TQM) education [7]:

- Formulate key qualifications/attainment targets.
- Utilize instructional methods that encourage students to take up active learning.
- Utilize practice situations recognizable to the students.
- Bring the outside in, and go outside in order to integrate knowledge and practice.
- Involve businesses in the development of programs and courses.
- Use interaction and feedback.

The institution should facilitate interaction with other students and lecturers, and, as a result, promote multiple feedback opportunities within the learning process. Guidelines for the application of TQM in educational institutions can be summarized as follows [7]:

- Provide training in an integrated system approach using quality management model and ISO-9000.
- Show commitment from the top.
- Include quality objectives in the regular policy cycle.
- Increase the visibility of objectives achieved and progress made.
- Complete the PDSA (plan-do-study-act) cycle.
- Provide role models in organizational and employee behavior.
- Recognize and respond to the needs of the customers – students, businesses, and government.
- Focus on continuous improvement.
- Study pioneers in quality.
- Learn the possibilities for contribution and participation as a function of willingness and skill.
- Use self-evaluation and external auditing.

Students and faculty, customer and business are all in the same boat in the long term – they are all life long learners.

Educational program outcomes are analogous to product quality characteristics in traditional production environment. Quality assurance in production requires the identification and measurement of these quality characteristics such as dimension, surface finish, etc., to further improve the production processes. Similarly, in an educational environment, suitable outcomes such as, the ability of the graduate to analyze data or to communicate effectively, are defined and monitored in order to identify opportunities for improving educational processes.

Comparisons between ISO-9000 and EC-2000 can be made by studying their similarities and differences. Engineering Criteria 2000 were developed through collaboration between academia and industry. Similarities between ISO-9000 and EC-2000 include: process emphasis, responsibility for quality, customer focus, documentation, inspection and testing, dealing with unacceptable product, internal quality evaluation, financial support for training, independent evaluation by external certified auditors, visit announcement, and length of certification and frequency of revisits. The differences include: quality characteristics, quality targets, contract review, process control, identifying training needs, after sales service, selection of evaluators, pre-assessments, and availability of help.

At present, ISO-9000 process is mature enough to provide guidance to the implementation of EC-2000. Lessons learned from ISO-9000 registration practice may provide the following useful guidance to the implementation of EC-2000: pay attention to documentation, but not at the expense of real educational reform; provide more EC-2000 training opportunities and expert advice; consider providing pre-assessment; institute training programs in teaching; and change faculty recognition and rewards system.

Continuous Improvement at MUSE

At MUSE, design and manufacturing courses are integral parts of industrial engineering education. At the junior level, students learn the basic concepts of manufacturing processes in ISE 370: casting, metal machining, plastics, electronic manufacturing, and introduction to automation and numerical control. In the manufacturing lab course (MAE 305L), students are introduced to theory and application of metal working machinery, industrial safety, engineering and technological aspects of joining operations, interpretation of engineering drawings, design of simple jigs and fixtures, and hands-on experience. In the computer assisted manufacturing course (ISE 424), fixed and flexible automation, computer aided process planning, computer control of manufacturing systems, group technology and cellular manufacturing, CAD/CAM integration, and programming on CNC machining center and numerically controlled devices are emphasized. They also work on term projects illustrating computer aided design and manufacturing concepts.

It has been decided to measure the continuous quality improvement in students' learning in the two courses (ISE 370 and ISE 424) using "*outcomes assessment*" model of engineering education accreditation (EC-2000). The "*inputs*" correspond to: selection of proper textbooks, catalog description of the course, learning objectives, and lab facilities. The "*processes*" focus on teaching methods/effectiveness, hands-on lab experiments, open-ended term projects, homework, class participation/discussion, periodic quizzes, teamwork, preparing for tests and final exams. The "*outputs*" are the effective learning measured through the comprehensive final exams average percentage scores. The students' evaluation, the faculty self-assessment, and the recommendation made by the faculty outcome assessment teams are used as feedback to continuous quality improvement in students' learning in the subsequent semesters.

***ISE 370*:**

In 1998, the catalog description for EGR 370 (an introductory course in manufacturing processes and management aspects in manufacturing) was as follows:

> Basic concepts of manufacturing systems and management applications in manufacturing. Manufacturing processes: casting, metal machining, plastics, electronic manufacturing, and introduction to automation and numerical control. Management aspects in manufacturing: forecasting, inventory control, aggregate planning, sequencing and scheduling, and project management.

The learning objectives for EGR 370: Upon successful completion of this course, the student should be able to do the following:

1. Demonstrate the basic concepts of manufacturing systems and management applications in manufacturing.
2. Describe the basic manufacturing processes such as casting, metal machining, plastic manufacturing, electronic manufacturing, automation and numerical control.
3. Participate in a team, design simple parts, write CNC programs using G-code, make parts on CNC machining center, and write lab reports.
4. Describe non-traditional machining processes, their merits and demerits.
5. Identify basic models of forecasting, inventory control, and project management and use them correctly for analyzing the data and interpreting the results.
6. Solve problems related to manufacturing processes, and management aspects in manufacturing.

The topics covered during the semester were: The manufacturing system; foundry processes; contemporary casting processes; basic machine tool elements; metal cutting; turning, drilling, boring, and milling machine tools; plastic materials and processes; electronic fabrication; nontraditional processes; quality systems; computer numerical control systems; process automation; forecasting; inventory control; and project management.

In the manufacturing laboratory, the students had an opportunity to learn programming in G-code, design and make simple parts in wax/wood on the CNC machining center. The students worked in groups of three on lab work. Video films on manufacturing processes such as casting, plastics processing, electrical discharge machining, abrasive machining, and electronic manufacturing were shown during the coursework for the students to understand the industrial environment related to the above processes.

The departmental review has considered feedback from the faculty who has taught the course, the students who have taken it, and the recommendations made by the Faculty Outcome Assessment Teams. Over the period of four years, the following changes have been made in the course content as well as in the lab work:

1. Remove management aspects in manufacturing: forecasting, inventory control, aggregate planning, sequencing and scheduling, and project management.
2. Add welding and joining processes, introduction to geometric dimensioning and tolerancing, metrology and testing, and process automation.
3. Add more hand-on experience in the integrated laboratory assignments.

The course title has been changed to ISE 370: Manufacturing Processes I. A new textbook has been adopted to reflect the changes in the course description. A five-axis robot (CRS Robotics: A255) and a coordinate measuring machine (Brown & Sharp) have been added to enhance the hand-on experience in measurement and automation.

ISE 424:

The catalog description for ISE 424 was as follows:

> Introduction to computer assisted manufacturing and automation. Fixed and flexible automation, computer aided process planning, and computer control of manufacturing systems. Introduction to robotics and robot programming. Group technology and cellular manufacturing systems. CAD/CAM integration. Integrated laboratory work: Programming on CNC machining center, and numerically controlled devices. Projects illustrating computer aided design and manufacturing. Programming robots. Design of work cells.

The learning objectives for ISE 424 (second level course in manufacturing for the industrial engineering students): Upon successful completion of this course, the student should be able to do the following:

1. Describe the fundamentals of numerical control, classification, and applications.
2. Analyze a numerical-control system: prime movers, transducers, interpolators, and DC motors
3. Participate in a team, design complex parts, write CNC programs using G-code, make parts on CNC machining center, and write lab reports.
4. Describe classification and applications of robots.
5. Analyze industrial robotics with reference to power sources, kinematics and dynamics, sensors and computer vision.
6. Solve problems related to process planning, group technology, and industrial robots.
7. Program 5-axis robots using teach pendent and computer interfacing and control.

The topics covered during the semester: Introduction to computer assisted manufacturing systems; fundamentals of numerical control; design of transducers, interpolators, and control loops; numerical control programming: G-codes; Industrial robotics; process planning: manual and computer aided process planning; group technology: classification and coding, part families, machine cells, and clustering algorithms; concurrent engineering and enabling technologies for concurrent engineering; integrated computer aided manufacturing: FMS architecture, and shop floor control; planning of manufacturing systems: manufacturing resource planning and machine requirement planning; programming on CNC machining center and CNC equipment; programming of 5-axis robotic devices and design of work cells; computer interfacing and control of robotic devices; and term project on computer aided manufacturing and robotics. The students had opportunity to learn programming CNC devices, and robots. They designed and made complex parts in wax/wood/metal on the CNC machining center. The students worked in groups of three on lab work.

Over the period of four years, the following changes have been made in the course content as well as in the lab work based on the departmental review:

1. Add more laboratory work on CNC machining center, numerical control machines, robots, and vision system.
2. Add more exercises on CAD/CAM integration.
3. Add a reference textbook on CNC Programming to help the students to learn effectively G-code programming for complex shapes and parts.

A five-axis robot (CRS Robotics: A255) and a coordinate measuring machine (Brown & Sharp) have been added to enhance the hand-on experience in measurement, reverse engineering, automation, and robot programming.

Results and Discussion

The results obtained during the four-year period on students' performance are presented and discussed in this section. The percentage class averages in the final examination for the two courses during four consecutive years (1998-2002) are shown in Table 2. The numbers in the parentheses indicate the number of students registered and completed the course. The results clearly indicate that the average percentage score in each course increased continuously irrespective of the class size. Figure 1 shows the comparison of final exams averages between ISE 370 and ISE 424. Other statistical data such as mean, median, range, and standard deviation for the two courses are summarized in Table 3. The correlation coefficient between these course averages is 0.996235 indicating consistency in the learning from introductory course, ISE 370 to second level course, ISE 424.

Table 2: Class averages during 1998-2001

	Percentage class average in the Final Examination Year			
Course	1	2	3	4
ISE 370	72.7 (20)	83.5 (08)	84.5 (29)	87.4 (13)
ISE 424	60.1 (10)	78.8 (09)	82.3 (12)	85.1 (07)

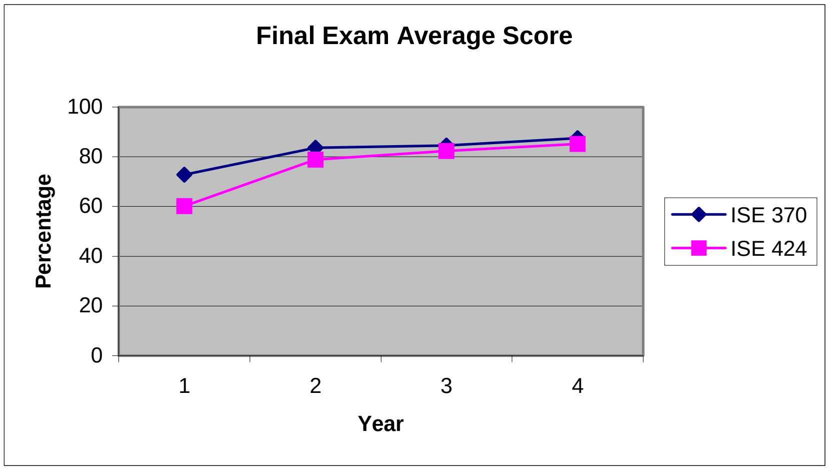

Figure 1: Comparison of final exam average between ISE 370 and ISE 424

Table 3: Statistical analysis of ISE 370 and ISE 424 class averages

Course	Mean	Median	Range	Standard Deviation
ISE 370	82.025	84.00	14.7	6.432923
ISE 424	76.575	80.55	25.0	11.281660

Conclusions

The higher education institutions must develop training programs that accept input from their faculty, students, and society as a whole. Lifelong learning and mutual, interactive learning are key terms in any innovative educational vision. The separation between the school and the professional world – between learning and working – is merely an artificial barrier. This barrier hinders learning through doing – the kind of learning that develops necessary skills and attitudes. The concepts of quality philosophy, quality tools, quality management, and quality function deployment along with ISO-9000 standards should be effectively used to monitor the quality of engineering education for continuous improvement. ISO-9000 quality assurance standard was developed in response to a need for providing worldwide quality to business. EC-2000 provides a systematic tool for quality assurance in engineering education. Some of the lessons learned in the ISO-9000 field should be extended to engineering education and EC-2000. These include focusing on the processes instead of the inputs and outputs, importance of documentation and training, and a need to reevaluate faculty reward systems. From ISO-9000, focusing on the processes as well as importance of documentation have been considered and applied in this study. The *"outcomes assessment"* model concepts of EC-2000 applied to two manufacturing courses showed continuous improvement in students' learning/performance at MUSE.

References

1. Brawner, C. E., Anderson, T. J., Zorowski, C. F. & Serow, R. C. (2001), "Quality Approach Supports Engineering Education Reform," *Quality Progress,* Vol. 34, No. 7, pp. 75-81.

2. Canic, M. J. & McCarthy, P. M. (2000), "Service Quality and Higher Education do Mix," *Quality Progress*, Vol. 33, No. 9, pp. 41-46.

3. Cornesky, R. (1993), *"The Quality Professor: Implementing TQM in the Classroom,"* Magna Publications, Inc., Madison, WI.

4. Fournier-Bonilla, S. D., Watson, K. L. & Malavé, C. (2000), "Quality Planning in Engineering Education: Analysis of Alternative Implementations of a NewFirst-Year Curriculum at Texas A & M University," *Journal of Engineering Education,* Vol. 89, No. 3, pp. 315-322.

5. Huband, F. L. (1998), *"How do you Measure Success? Designing Effective Process for Assessing Engineering Education,"* ASEE Publications, Washington D. C.

6. Juran, J. M. & Godfrey, A. B. (1999), *"Juran's Quality Handbook,"* McGraw-Hill, New York, Fifth Edition.

7. Kemenade, E. V. & Garre, P. (2000), "Teach What You Preach: Higher Education and Business: Partners en Route to Quality," *Quality Progress,* Vol. 33, No. 9, pp. 33-39.

8. Lamprecht, J. L. (1992), *"ISO 9000: Preparing for Registration,"* ASQC Quality Press, Milwaukee.

9. Lohmann, J. R. (1999), "EC 2000: The Georgia Tech Experience," *Journal of Engineering Education,* Vol. 88, No. 3, pp. 305-310.

10. Montano, C. B. & Utter, G. H. (1999), "Total Quality Management in Higher Education: An Application of Quality Improvement in a University," *Quality Progress,* Vol. 32, No. 8, pp. 52-59.

11. Peach, R. W. (1997), *"The ISO 9000 Handbook,"* Richard D. Irwin, Chicago.

12. Rogers, G. M. (2000), "EC2000 and Measurement: How Much Precision is Enough?" *Journal of Engineering Education,* Vol. 89, No. 2, pp. 161-165.

13. Sarin, S. (2000), "Quality Assurance in Engineering Education: A Comparison of EC-2000 and ISO-9000," *Journal of Engineering Education,* Vol. 89, No. 4, pp.495-501.

14. Winchell, W. (1991), *"Continuous Quality Improvement: A Manufacturing Professional's Guide,"* SME, Michigan.

R. Radharamanan

Dr. R. Radharamanan is a Professor of Industrial and Systems Engineering in the Department of Mechanical and Industrial Engineering at Mercer University in Macon, Georgia. He has twenty-five years of teaching, research, and consulting experiences. His previous administrative experiences include: President of International Society for Productivity Enhancement (ISPE), Acting Director of Industrial Engineering as well as Director of Advanced Manufacturing Center at Marquette University, and Research Director of CAM and Robotics Center at San Diego State University. His primary research and teaching interests are in the areas of manufacturing systems, quality engineering, and product and process development. He has organized and chaired three international conferences, co-chaired two, and organized and chaired one regional seminar. He has received two teaching awards, several research and service awards in the United States and in Brazil. His professional affiliations include ASEE, IIE, ASQ, SME, ASME, and ISPE.